Expeditionary C5 Grid (EC5G) FY 02 Limited Objective Experiment

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ABSTRACT
The Expeditionary Command, Control, Communications, Computer, Combat System Grid (EC5G) project is working to transform network-centric warfare concepts into operational practice. EC5G's primary effort for fiscal year (FY) 02 was a laboratory-based limited objective experiment (LOE) designed to investigate FY 06-07 mission capability enhancement using a global Internet Protocol (IP) architecture design that integrated a tactical shore backbone with satellite communications (SATCOM), line-of-sight, and information security. The approach was a comprehensive set of IP networking experiments conducted on a laboratory architecture built to model key components of a mini-fleet network. LOE accomplishments included designing and validating a layered network architecture that enables seamless worldwide mobility for naval forces, validating the value of such a network for the seamless transport of time-critical targeting data, validating quality-of-service designs and policies that distribute traffic over multiple SATCOM paths and prioritized traffic on a congested network, validating strategies for IP to the cockpit and ship-to-ship line-of-sight/beyond line-of-sight networking, and validating mechanisms for ad-hoc, any-to-any connectivity for security enclaves.

INTRODUCTION

The Expeditionary Command, Control, Communication, Computer, Combat System Grid (EC5G) initiative is the information transport cornerstone of the Navy's FORCEnet initiative. With a focus on time-critical strike and warfare capability improvement, EC5G is part of the U.S. Navy's effort to rapidly field a fully netted, global, adaptive, secure Internet protocol (IP) network for the naval and joint forces. EC5G is embarked on a multi-year process of experimentation; rapid prototyping; tactics, techniques, and procedures development; and program of record transition. Key collaborators for the limited objective experiment (LOE) described here included the Advanced Deployable System (ADS) program and the Office of Naval Research's (ONR's) Fleet Enterprise Network (FleetNet) Project, part of the Knowledge Superiority and Assurance Future Naval Capability (KSA FNC) program.

EC5G's primary effort for FY 02 was a laboratory-based LOE designed to investigate the 2007 capability potential of a global IP network and security architecture. The LOE hypothesis was that warfighting effectiveness could benefit from a converged IP network featuring end-to-end, global IP quality-of-service (QoS) support for high-priority, tactical traffic. The design objective was a global routing model that could naturally stem from and leverage the Navy's investment in Cisco routing technology that the ADNS program is installing on ship and shore nodes. The QoS design objective was end-to-end support for priority IP traffic and multiple security enclaves sharing the same network over KG-175 (FASTLANE® or TACLANE) IP-encryption devices.

LOE OVERVIEW

The LOE consisted of a comprehensive set of IP networking experiments conducted on a laboratory architecture built to model key components of a global force network. The LOE network was designed to resemble a scaled-fleet network (Figure 1), including three shore nodes, six ship nodes, two aircraft nodes, three military satellite communication links to each ship, two Joint Tactical Radio System (JTRS) line-of-sight (LOS) networks, a beyond line-of-sight (BLOS) network relay, tactical communications data link (TCDL) point-to-point links from ship and air nodes, and three independent network security domains. Specific hardware included 45 Cisco routers, 20 Cisco switches, 65 PCs, 2 SATCOM

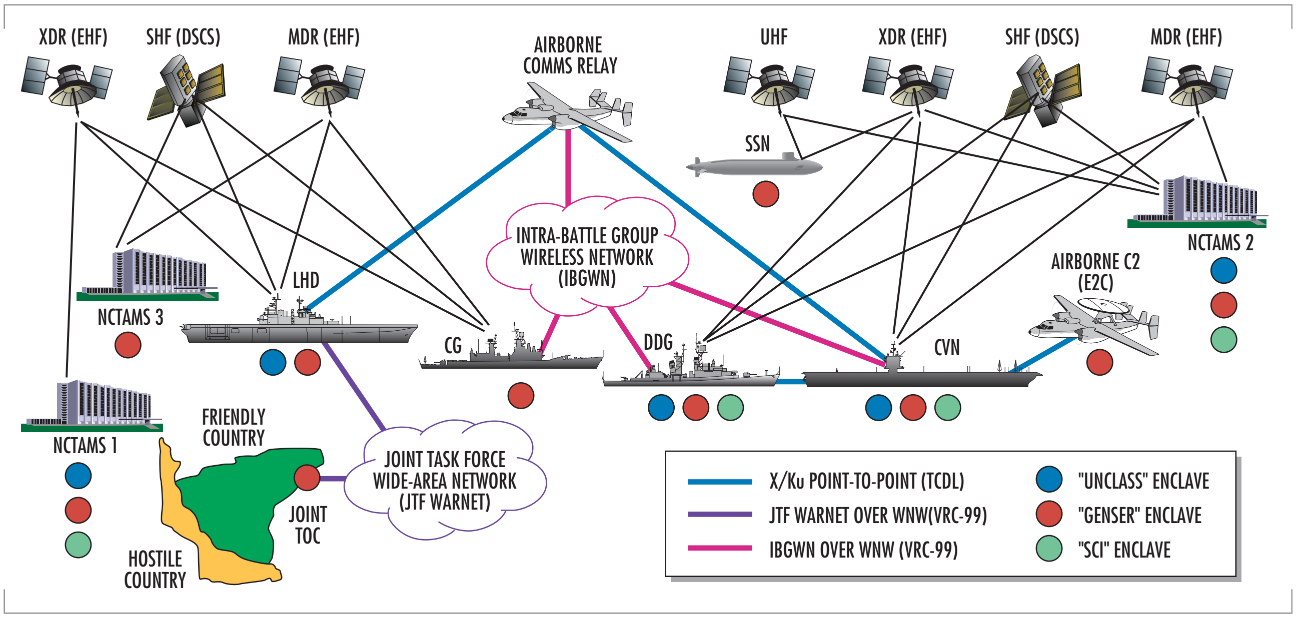

FIGURE 1. The EC5G LOE built a laboratory model of a next-generation global IP network for the Fleet. The LOE investigated technical integration issues as well as operational value brought to the warfighter.

simulators, 12 TACLANEs, 8 VRC-99 radios, and 2 programmable advanced transmission) multiplexers. The LOE network was distributed between five laboratory locations at SSC San Diego, connected seamlessly via virtual local-area networks over fiber.

Individual network experiments were designed as sub-tests to investigate specific network performance concerns. The 11 focus areas were:

1. Prioritized Network Traffic – guaranteeing network capacity in presence of congestion.
2. Latency-Bound Delivery Service – for high-priority service.
3. Load Distribution – to fully use every available link off a platform.
4. Ship-to-Ship LOS and BLOS Networking – for seamless QoS.
5. Airborne IP Services – to provide high-capacity Secret Internet Protocol Router Network (SIPRNET) to aircraft nodes.
6. Global Information Transfer (Network Operations Center [NOC]-to-NOC) – for transfer of time-critical strike data.
7. IP Network Encryption – to support global domains and policies.
8. Embedded Firewalls – for Layer 3 security access and control.
9. SATCOM Crosslink – to investigate inter-area of responsibility (AOR) routing and information assurance.
10. Joint IP Connectivity – to show integrated IP routing between Navy and joint nets.
11. End-to-End Scenario – to exercise global QoS policy and architecture.

Network routing and QoS architectures, operational scenarios, measures of effectiveness (MOEs), measures of performance (MOPs), and data collection approaches were designed to support the 11 focus area experiments.

NETWORK DESIGN

The current afloat network is based on single or multiple routing domains per AOR. Per AOR routing means that direct network discovery and communications cannot be provided between ships or shore resources in different AORs. EC5G implemented a layered, global routing architecture using enhanced interior gateway routing protocol (EIGRP) and a single autonomous system for all general service (GENSER) network routers. A routing hierarchy design was implemented that includes three layers. The "core" network layer includes the NOC routers that receive all routing updates and know all SATCOM routes to every ship. The "media" layer includes shore routers that route traffic from a core router through a particular SATCOM system. A media router is only aware of nodes attached to that SATCOM system. The "ship" layer routers are responsible for routing all IP traffic (via SATCOM or LOS) on and off of the ship. This layered routing approach enabled implementation of a single global Navy routing domain while maintaining minimum routing updates to ships. Minimizing routing updates to ships provides optimized network convergence, reduces route traffic overhead, and simplifies network management.

OPERATIONAL SCENARIO

The LOE scenario featured a rapid deployment of two battle groups (BGs) from different AORs. The BGs conducted initial planning for the battle enroute, conducted time-critical strike missions in theater, and operated together while communicating via different naval computer and telecommunications area master station (NCTAMS) and LOS links. The ships worked seamlessly and automatically through the global net as they moved around the world conducting network-centric warfare. For the Focus Area 1 experiments, for example, the CVN (aircraft carrier, nuclear) communicated with NCTAMS2 and switched between a combination of three different satellite resources at different times, providing guaranteed minimum capacity for several classes of marked IP traffic types (Figure 2).

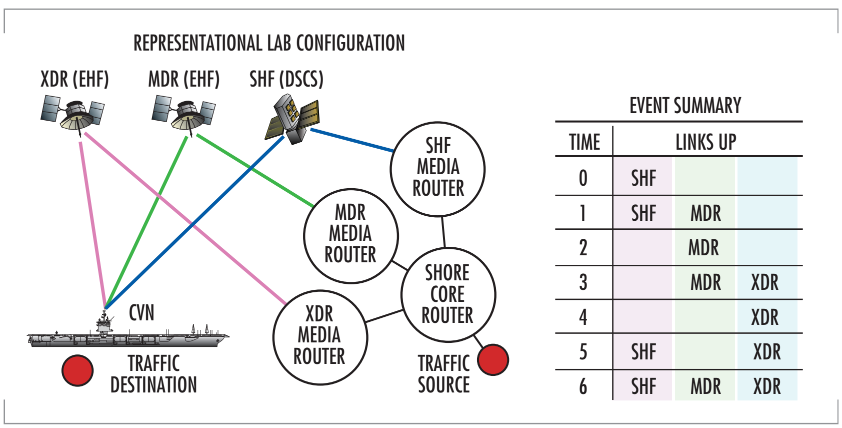

FIGURE 2. The LOE Focus Area 1 investigated priority-based routing of IP traffic over multiple SATCOM links to a ship.

DATA COLLECTION AND ANALYSIS

Experimental data were collected using Chariot, a tool that emulates network users by sending traffic over the network; PacketShaper®, a tool that identifies traffic on the network at a localized node; and Cisco Quality of Service Device Manager (QDM), a browser-based application that runs from Java™. QDM is used to monitor and configure IP-based QoS functionality within Cisco routers. The combination of these three tools facilitated the development of scenario-based MOEs and MOPs for assessing the ability of the network to support warfighting needs. Specific metrics included throughput samples, response time, one-way-delay, and transaction rate samples using the Chariot tool; traffic bandwidth by type and channel-utilization statistics using the PacketShaper tool; and traffic rate per QoS class using the QDM tool.

EXPERIMENTAL RESULTS

One of the Focus Area 1 (prioritized network traffic) experiments is well suited for conveying a flavor of the LOE. The objective of this experiment was to guarantee a minimum, seamless capacity for high-priority IP traffic on a congested, dynamic, multi-link network. The scenario tested the network's ability to provide traffic prioritization, distribution, and fail-safe redundancy using multiple radio frequency (RF) satellite links during communications between NCTAMS2 and the CVN.

The Focus Area 1 experiment focused on IP traffic flow between a shore core router (NCTAMS2) and the CVN connected by three satellite links (expanded data rate [XDR], medium data rate [MDR], super high-frequency [SHF]). The three satellite links were taken up and down in an order that routed traffic over different combinations of links (Figure 2). Six IP traffic types were marked with differentiated services code point (DSCP) tags. Priority-based routing was implemented on the routers using class-based weighted fair queuing so that each class of traffic enjoyed reserved capacity on all three SATCOM links and each had a preferred link when that link was available. The six traffic types used for this experiment were Naval Fires Network (NFN), Joint Services Imagery Processing–Navy Consolidated Architecture (JCA), Joint Worldwide Intelligence Communications System (JWICS), voice over Internet protocol (VoIP), video over Internet protocol (VIDoIP), and default. Each traffic type had a guaranteed minimum capacity in each SATCOM link, but each was assigned a preferred link. When the assigned link was not available, the traffic was rerouted to a different SATCOM link. The preferred link for JCA, VoIP, and default traffic was the SHF link. When the SHF link was not available, these traffic types defaulted to the XDR link. The preferred link for NFN and VIDoIP traffic was the XDR link, and the preferred link for JWICS traffic was the MDR link. When the MDR link was not available, JWICS defaulted to the SHF link.

Figures 3, 4, and 5 describe the traffic flow results through each one of the satellite links: SHF, MDR, and XDR, respectively. At t0, only the SHF link was up. Consequently, all traffic was routed via the only available link. At t1, both the SHF and the MDR

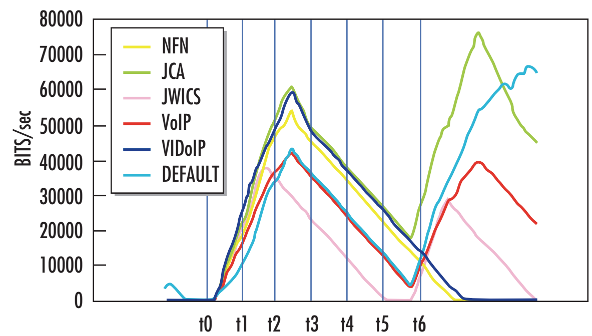

FIGURE 3. Moving-average IP traffic flow rate through the SHF SATCOM link. Traffic classes are provided a minimum guaranteed capacity in conjunction with a routing policy scheme.

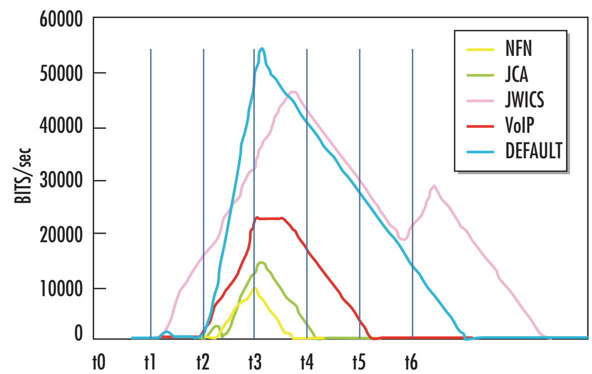

FIGURE 4. Moving-average IP traffic flow rate through the MDR SATCOM link.

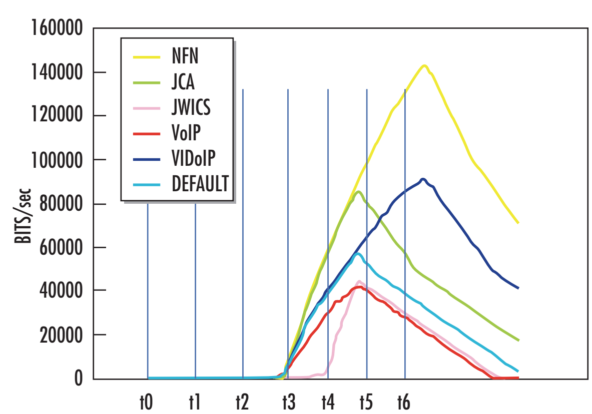

FIGURE 5. Moving-average IP traffic flow rate through the XDR SATCOM link.

links were up. At this time, JWICS traffic was routed via the MDR link since it was the preferred link. At t2, the SHF link was down and all traffic was now routed via the only available link, the MDR link. The graphs indicate link up and link down processes as a "ramp up" and "ramp down" effect, respectively. This is because the QDM tool computes a moving-average throughput. A 300-second moving average was used in this experiment. At t3, the XDR link was brought up. At this time, all traffic shifted to the XDR link except for the JWICS traffic. At t4, the MDR link was down, and all traffic was routed via the XDR link. At t5, both the SHF and the XDR links were up. At this time, JCA and VoIP traffic were routed via the SHF link, NFN and VIDoIP traffic were routed via the XDR link, and JWICS traffic was routed via the SHF link. At t6, all SATCOM links were up and all traffic was routed via the originally assigned default links. QDM data were found to be well correlated with the time logs for all three satellite links. This experiment demonstrated the ability of the network to reliably reroute traffic, depending on the availability of links with a guaranteed minimum throughput.

Overall, the LOE produced a number of significant routing design results. For example, a simple, scalable network design was accomplished with very short routing tables on all the ships, with routing tables consisting of only a default route, local-area networks, and LOS/BLOS networks. Router logs showed that ship route changes did not propagate to other ships except LOS-attached ships. Test scripts run in the global information transfer focus area showed seamless automatic routing and re-routing for global connectivity regardless of the AOR connections for ships. Global network convergence was under 30 seconds in various test scenarios.

SUMMARY

LOE overall results supported the feasibility of a single-domain routing concept for the Fleet that is responsive to the time-critical information needs of the warfighter. LOE accomplishments included designing and validating a layered network architecture that enables seamless worldwide mobility for naval forces, validating the value of such a network for the seamless transport of time-critical targeting data, validating QoS designs and policies that distribute traffic over multiple SATCOM paths and prioritized traffic on a congested network, validating strategies for IP to the cockpit and ship-to-ship LOS/BLOS networking, and validating mechanisms for ad hoc, any-to-any connectivity for security enclaves. As one of the Navy's initial efforts to transform the concepts for network-centric warfare into operational practice, the EC5G LOE exemplifies work in SSC San Diego’s strategic imperative area of Dynamic Interoperable Connectivity.

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